Shotcrete Use in the Gold King Mine Rehabilitation

By Christoph Goss

The Gold King Mine Level 7 Portal is located at elevation 11,438 ft (3486 m) on the North Fork of Cement Creek, approximately 8 miles (13 km) north of Silverton, CO. From the mid-1890s until the start of World War I, the Gold King was a major producer of gold, silver, lead, zinc, and copper. During that time, it had two aerial trams, boarding house, shop, and a dedicated mill in the valley below. The mine itself consists of seven underground levels connected by a vertical shaft. The only levels that connect to the surface are Level 1 at elevation 12,160 ft (5516 m) and Level 7. Level 7 served as the main haulage and drain level during the mine's most productive years. In the 1980s, a second horizontal opening (adit) was driven into Level 7 to allow mine rehabilitation and mineral exploration, but this effort was abandoned after a few years. The Gold King Mine regained "fame" in 2015 when an uncontrolled release of mine drainage made national news. While much has been publicized about the release, very little has been said about the steps taken to rehabilitate and stabilize the mine since then.

PROJECT CHALLENGES

Many of the challenges on this project centered around access. The nearby town of Silverton is reachable by only two roads, both of which cross high mountain passes. From Silverton, an unpaved county road leads to the abandoned town site of Gladstone. From Gladstone, a narrow unpaved county road leads to the site—a waste dump and portals on a south-facing mountainside slope with a steep (approximately 60%) grade. The site is accessible only during non-snow months of the year, typically late June through early October. Even during those months, the road width and sharp curves severely limit the size and type of equipment that can access the site.

Figure 1 shows the portal area shortly after the 2015 release. The jointed, strongly altered rock hung precipitously over the open channel where timber sets had once stood. Looking into the old workings, one could see failed rock bolts, rusty mine straps, and a high "cathedral" in the back (roof). Given the instability of the ground and the short time before winter would arrive, it was critical to design a rehabilitation that was flexible, resistant to mine water, and used "off the shelf" material. A system of shotcrete and rock bolts was quickly selected. The underground contractor, Harrison Western out of Lakewood, CO, mobilized to the site a few weeks later. They laid back the slopes around the portal and installed temporary split set rock bolts along with welded wire fabric. They continued the work into the underground, scaling and bolting their way past the cathedral.

INITIAL STABILIZATION OF THE PORTAL

The next phase of work was shotcrete around the portal. Harrison Western chose to use the dry-mix process. The material was provided in supersacks by Thiessen Team. The mixture consisted of 650 lb (295 kg) Type II/V cement, 100 lb (45 kg) fly ash, 65 lb (29 kg) silica fume, sand, pea gravel, and accelerator. Some bags came with polypropylene fibers at 12 lb/yd^3 (7 kg/m^3). Given the high altitude of the site, an 825 ft^3/min (23 m^3/min) air compressor was needed.

Fig. 1: Portal before rehabilitation

Fig. 2: Portal area excavated and initial support in place

Fig. 3: View into cathedral behind portal

The shotcrete application went very well thanks to skilled miners with significant shotcrete experience. The crew hand nozzled and used a manlift to access the slope. The final support consisted of an initial shotcrete layer 2 in. (50 mm) thick, followed by No. 8 Dywidag resin bolts, and a second layer of shotcrete 4 in. (100 mm) thick.

The initial design for the underground support was the same shotcrete and bolting used at the portal. Based on requests by the client, the final underground support in the first 64 ft (20 m) was changed to fully lagged steel sets backfilled with cellular concrete. To allow safe construction of the steel sets, 2 in. of shotcrete was applied to the upper ribs and back to reinforce the bolts and mesh. This is shown in Fig. 2, 3, and 4. Note the 30 ft (9 m) high cathedral back in Fig. 3. For comparison, the original dimensions of the adit were approximately 10 x 10 ft (3 x 3 m).

SUPPLEMENTARY STABILIZATION

After the initial stabilization in 2015, Harrison Western remobilized in 2016 to complete the work. This included the steel

Fig. 4: Installing steel sets under initial shotcrete support

Fig. 5: Shotcrete placement in high back

sets and backfill. Concurrently, the team evaluated ground conditions further in the mine. Approximately 100 ft (30 m) into the mine, another high back cathedral 27 ft (8 m) high was discovered. Failed mine straps and rock bolts were visible around it. To avoid a new collapse in this area, it was decided to fully support the mine to just past this point. Advance was difficult due to the presence of sludge and debris 5 ft (1.5 m) thick on the floor. The material consisted of sand, gravel, cobble sized rock blocks, old pipes and cables, and orange metal precipitate with a pudding-like consistency. Harrison Western mucked out this material, scaled the ground, and installed No. 8 Dywidag resin bolts with welded wire fabric. Next, they placed 4 in. of shotcrete in two lifts. This time they elected to use the wet-mix process. Alpine Mobile Crete (AMC) from Durango, CO, mobilized a volumetric mixer truck to the mine portal. During the initial shotcrete placement, AMC adjusted the mixture design until they had a mixture that pumped well and stuck to the back and ribs without requiring an accelerator. The final mixture included 790 lb (360 kg) Type II/V cement, 165 lb (75 kg) fly ash, 72 lb (33 kg) silica fume, sand, and pea gravel.

Figure 5 shows the shotcrete placement in the second high back area. Figure 6 shows the initial layer of shotcrete looking in while Fig. 7 shows the final layer looking out. In Fig. 8 one can see the final shotcrete in the second high back cathedral area along with wood/concrete cofferdams to hold back the sludge and debris. Also visible in the figures is the hose from the bypass pump that pumped water from the mine pool to the treatment plant, keeping the work area dry. Figure 9 shows the portal area at the completion of the project. Thanks to the skilled nozzlemen who used a good mixture and appropriate equipment, the shotcrete placement went very well, meeting all design specifications.

Fig. 6: Initial layer of permanent shotcrete support

Fig. 7: Final layer of permanent shotcrete in place

Fig. 8: Final shotcrete in place at high back

Conclusions

The use of shotcrete, both dry and wet mix, was a critical component of the successful rehabilitation of the Gold King Mine. It allowed for a rapid response in a remote alpine area where varied types and amounts of support were required. Now that this ground support and other components of the rehabilitation are complete, the mine has been stabilized and all parties can focus on long-term solutions. The Gold King Mine is now part of the EPA's Bonita Peak Superfund site. More information about the project can be obtained from EPA. For more on the history of the mine, see the new book published by the San Juan County Historical Society, *The King of the Spill: The Gold King Mine* by David L. Thayer and Douglas R. Thayer.

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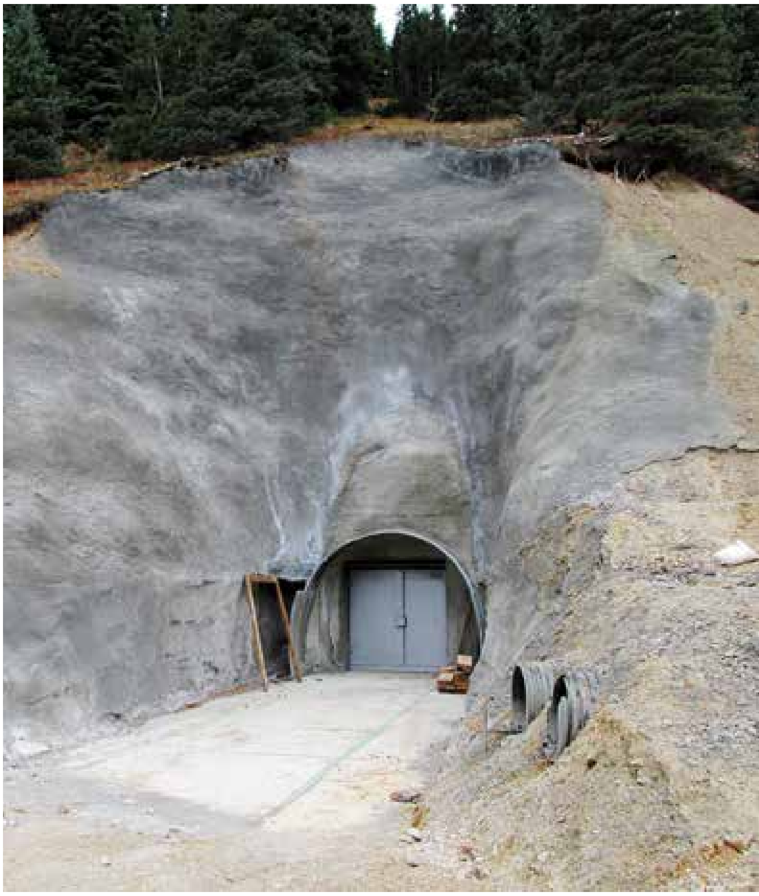

Fig. 9: Portal at completion of project